Fisheries and Oceans Canada | Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/204

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Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/204

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Life history of Pacific sardine and a suggested framework for determining a B.C. catch quota

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ISSN 1480-4883
Ottawa, 1999
Canada

104-00126/

ABSTRACT

Tagging studies indicate that the sardines which range from British Columbia in the summer, to southern California in the winter belong to the same stock: the northern population. The oldest age-groups of sardine in this stock migrate northward from California to B.C. in the summer, and complete a return migration in the fall. The migratory behaviour of sardine is complex and poorly understood. However, one generalization that emerges from historical and recent accounts is that sardines are particularly abundant off B.C. in warm summers when the northern population biomass exceeds 1 million tonnes. Both conditions appear necessary to produce a large run. Historically, an average of 10% of the northern stock appears to have migrated to B.C. The actual percentage varied from year-to-year in response to changes in water temperature, and other factors. The U.S. is currently harvesting the portion of the northern stock available to the California fishery at a rate of 5 to 15%. To be precautionary, the Canadian fishery should harvest the resource at similar rates, which would average about 10% of the biomass in Canadian waters. At current stock levels, and assuming a 10% migration rate the B.C. fishery could potentially harvest about 12,700 tonnes. However, for management reasons such as: 1) an undesirable bycatch of sensitive species like coho and chinook salmon or; 2) the appearance of sardines in sensitive (or unfishable) areas it may be advisable to set a lower quota for a few years, until the B.C. sardine fishermen become more experienced, and the bycatch risks associated with the fishery are more clearly understood. DFO must make it very clear to the industry from the outset that the allowable catch is a ceiling, not a target. Because of the dynamic and unpredictable movements of this highly migratory species there is no guarantee that the B.C. sardine fleet will catch the annual quota. Industry must also be aware that sardine undergo large fluctuations in abundance in response to variations in ocean climate. Accordingly, if the current favourable conditions begin to deteriorate the sardine could 'disappear' from the B.C. coast (for a while at least), like they did in the late 1940s. Regardless of whether a preseason or inseason biomass estimate is used to determine the total allowable catch, soundings should be conducted in inshore waters to assess the relative biomass of sardines in the area before a fishery commences. Even though sardine are highly migratory, all the catch should not be removed from one area. This requirement recognizes that sardine is a potential forage-fish in the ecosystem.

RÉSUMÉ

Les résultats d'expériences de marquage montrent que les sardines qui s'étendent sur une superficie allant de la Colombie-Britannique en été jusque dans le sud de la Californie en hiver font partie du même stock, c'est-à-dire la population nordique. Les sardines de ce stock appartenant aux groupes d'âge les plus âgés migrent vers le nord à partir de la Californie jusqu'en C.-B. en été et migrent à rebours à l'automne. Le comportement migratoire des sardines est complexe et mal connu. Toutefois, les observations passées et présentes nous permettent de faire la généralisation suivante : les sardines sont tout particulièrement abondantes au large de la C.-B. lorsque les étés sont chauds et lorsque la biomasse de la population nordique dépasse 1 million de tonnes. Pour que la remontée soit abondante, il semble que ces deux conditions doivent être réunies. Par le passé, une moyenne de 10 % du stock nordique semble avoir migré vers la C.-B. Le pourcentage réel varie d'une année à une autre suivant les changements de température de l'eau et d'autres facteurs. Les É.-U. récoltent actuellement la partie du stock nordique mise à la disposition des pêcheurs en Californie, c'est-à-dire à un taux de 5 à 15 %. En guise de précaution, les pêcheurs canadiens devraient récolter la ressource à des rythmes semblables qui représenteraient en moyenne environ 10 % de la biomasse présente dans les eaux canadiennes. Si le stock se maintient à son niveau actuel et si le taux de migration est de 10 %, les pêcheurs de la C.-B. pourraient récolter environ 12 700 tonnes. Toutefois, pour des motifs de gestion tels que 1) des prises accessoires involontaires d'espèces fragiles telles que le saumon coho et le saumon quinnat ou 2) l'apparition de sardines dans des zones fragiles (ou non exploitables), il serait peut-être souhaitable de fixer un quota plus faible pendant quelques années jusqu'à ce que les pêcheurs de sardines de la C.-B. soient plus expérimentés et que l'on comprenne mieux les risques de prises accesssoires associés à la pêche. Le MPO doit, dès le départ, expliquer très clairement à l'industrie que les captures admissibles constituent un plafond et non pas un objectif à atteindre. Compte tenu des mouvements dynamiques et imprévisibles de cette espèce très migratoire, rien ne garantit que la flottille de pêche de la sardine de la C.-B. capturera le quota annuel fixé. Par ailleurs, on doit informer l'industrie que l'abondance de sardines varie considérablement suivant les variations du climat océanique. Ainsi, si les conditions favorables qui existent actuellement commencent à se détériorer, les sardines pourraient « disparaître » de la côte de la C.-B. (du moins, pendant un certain temps), comme ce fut le cas vers la fin des années 1940. Peu importe qu'on ait recours ou non à une estimation d'avant-saison ou en cours de saison de la biomasse pour déterminer le total des prises admissibles, on devrait effectuer des relevés par échosondage dans les eaux côtières pour évaluer la biomasse relative de sardines dans une zone avant le début de la pêche. Même si les sardines sont très migratoires, on ne devrait pas prélever toutes les prises dans une zone. Ainsi, on tiendrait compte du fait que les sardines peuvent servir de poisson fourrage dans un écosystème.

LIFE HISTORY

Biomass estimates reconstructed from scale deposits in marine sediments off southern California indicate that the sardine population in the northeast Pacific undergoes large fluctuations in abundance about every 60 to 80 years (Ware and Thomson 1991, Baumgartner et al 1992). Over the last two thousand years, the sardine biomass has ranged from less than 50 thousand tonnes to a peak of about 16 million tonnes. During the last period of abundance (1885 to 1945) the population biomass peaked around 8 million tonnes. Pacific sardine (also called pilchards) were last abundant in British Columbia from the mid-1920s to mid-1940s. During this period, tagging, meristics and growth studies were conducted to identify sardine populations along the west coast of North America. The results indicated that the fish which ranged from British Columbia in the summer, to southern California in the winter belong to the same stock: the northern population (Figs. 1 and 2). This population spawns from January to September, but primarily from April to June, in southern California in areas where water temperatures range between 15 to 18 °C. The sardine's minimum temperature threshold for spawning is about 13° C. During their first summer, young sardine move landward (or are passively carried there by the currents). Most of these young fish concentrate in a narrow band along the southern California coast, where they tend to spend their first two years of life.

Northern spawnings also occur near the Columbia River. An estimated 50,000 tonnes of sardines have spawned there in recent years (Bentlet et al 1996). Small numbers of sardine eggs and larvae were also found in plankton samples off the southwest coast of Vancouver Island in July, August and September 1992, and in August 1993 (W. Shaw, Department of Fisheries and Oceans). However, it is unclear if these early life stages originated from spawnings in Canadian waters, or if they had drifted into the area from northern Washington State. Successful spawnings were observed on the continental shelf and in some inlets along the west coast of Vancouver Island during the exceptionally warm El Niño summer of 1997 (Richard Leo and Sandy McFarlane (DFO), pers. comm.).

Prior instances of successful sardine spawnings in southern British Columbia have also been reported. Williamson (1930, Pacific Biological Station unpublished report) observed that "in June and July, some schools of sardines were captured which...were preparing to spawn. There seems reason for inferring that [they]...spawn in the vicinity of the B.C. coast. At different times, but not every year, small-sized sardines (7 to 9 cm long) have been reported...in Clayoquot Sound, Hesquiat and Malksope Inlet, and they are recorded as having been taken at Nootka Sound this year [1929]".

In the summer of 1940, large numbers of one year old sardine (7 to 10 cm long) appeared along the west coast of Vancouver Island (WCVI), Strait of Georgia, the central coast, and east coast of the Queen Charlotte Islands (Hart 1943b). These fish were part of the exceptionally strong 1939 year-class, which was the last significant year-class produced by the northern sardine stock before it collapsed in the mid-1940s (Radovich 1982). Considering the limited distances juvenile sardines migrate, the one-year old fish which appeared along the coast in 1940 are believed to have originated from a successful northern spawning in the spring or early summer of 1939 (Hart

1943b). The young sardine that entered the Strait of Georgia in the summer of 1940 experienced high mortalities that winter.

Seasonal Migration. Early tagging studies confirmed that the older fish in the population migrate poleward each year in the late spring, and undertake a return, equatorward migration in the autumn. With each year of life sardine travel further north. Consequently, the oldest (and largest) fish reached the west coast of Vancouver Island in the summer. The schools migrated at speeds of about 11 to 14 km /day, and typically arrived in southern Canadian waters between the middle of June and end of July. The sardines that migrated to B.C. ate small planktonic organisms, primarily diatoms and copepods. Sardines typically foraged along the west coast of Vancouver Island until mid-September to mid-October, when they began migrating south to spawn (Hart 1943b). This fall migration may be triggered by the seasonal transition in the prevailing winds, which change from an upwelling-favourable (northwesterly) direction to a downwelling-favourable (southeasterly) direction about this time. This return movement of the population closed the annual feeding- spawning migration cycle.

Although it was clear that the main body of sardines left Canadian waters in the autumn, "some fish frequently remained in the inlets throughout the winter", and were occasionally captured during the herring fishery (Hart 1943a). A recent example of this occurred in the winter of 1992/93. Ron Tanasichuk (a DFO biologist) found two sardines mixed with herring during the March 1993 roe herring test fishery in the Lambert Channel/Baynes Sound area, near Comox B.C. One sardine was a 23 cm male, with developing gonads. A few years later, in the winter of 1995/96, an estimated 5,000 tonnes of sardines were discovered overwintering along the outer west coast of Vancouver Island, around Nootka Sound (Richard Leo, pers. com.). In November 1997 about 10,000 tonnes of sardines were sighted in Kyuquot Sound (J. Lenic, pers. com). However, only a few hundred tonnes remained when Mr. Lenic revisited the area a few months later in January. In early February 1998, a significant mortality of sardines occurred in Takush Harbour in Smiths Inlet. This indicates that a large body of fish attempted to overwinter in this area following the exceptionally warm summer of 1997.

Summer Distribution. Hart (1973) noted that sardines occurred "most regularly in the summer on the west coast of Vancouver Island, south of Brooks Peninsula, less frequently in or off Quatsino Sound, and infrequently in the central part of the coast". In 1931, sardines migrated further north than usual. They were sighted off the central coast, east coast of the Queen Charlotte Islands, and in northern B.C. near the Skeena and Nass Rivers (Hart 1943b). In 1936, a large percentage of small (two-or three-year old) sardines appeared in the Canadian fishery. This was most unusual and was the subject of considerable comment among fishermen at the time (Western Fisheries, May 1937, p.13). Sardines also migrated further north than usual in the summers of 1936, 1939, 1941, 1942 and 1943. These were years of above average water temperatures along the coast, and included the protracted 1939 to 1941 El Niño event. The most recent example of this extended northward migration of sardines in warm El Niño summers is the appearance of some fish off the west coast of Vancouver Island in 1992 and 1993 (Hargreaves et al 1994), and much larger numbers in the summers of 1997 and 1998. The summers of 1997 and 1998 were abnormally warm off the west coast of Vancouver Island, and significant quantities of sardines were found offshore during DFO stock assessment trawl

surveys. Sardines were also caught in Barkley Sound, and were reported to be in some of the other large Sounds along the west coast of Vancouver Island.

The B.C. sardine fishery failed in 1933 and 1939. The summer of 1933 was unusually cold and the sardines didn't arrive. In contrast, during the unusually warm summer of 1939 there was an extended northward migration. Large numbers of sardines were caught around Rivers Inlet and Bella Coola during the summer and fall of that year. This is the first time sardines were harvested commercially north of Vancouver Island. Presumably the fishery failed because most of the sardines had migrated past the usual fishing grounds along the west coast of Vancouver Island into Queen Charlotte Sound. These observations indicate that the movements of sardine are affected by water temperature (and other factors). Modern satellite images reveal a large, plume of cool, upwelled water along the north-western tip of Vancouver Island in the summer. The cooler temperatures in this area may explain why warm-water species like sardines were infrequently found there; and why few sardines appeared in Canadian waters in cool summers in general.

THE FISHERY

Pacific sardines dominated the west coast of North America fisheries in the first half of this century. Huge quantities were reduced to fish meal and oil, and some were canned. The 1887 Canadian Dept. of Fisheries and Marine Report notes that sardines "were plentiful during the months of August and September in all harbours near the Straits [of Juan de Fuca] especially at Esquimalt". Since, sardines were not mentioned again in this report series until 1917 it appears they were either absent, or at least not very plentiful, in B.C. from 1890 to 1917. Coastal temperature records indicate a cooler climate at that time (Ware 1995), probably too cool for sardines. The first organized sardine fishery occurred in 1904 in Monterey, California (Hart 1937). The Canadian sardine fishery began in 1917, when a small quantity was canned; the large-scale reduction fishery began in 1925. Over the next eighteen months, fifteen reduction plants were built along the west coast of Vancouver Island. The increasing demand to supply these plants, required the Canadian fleet to move from the Inlets to the open Pacific to obtain high catches. Sardine schools were spotted up to 100 miles off the coast. The Canadian fleet fished frequently in the vicinity of Swiftsure Bank, and as far south as Destruction Island in Washington State (Western Fisheries, May 1937: 9-13). The B.C. fishery was intense but short-lived, lasting only 22-yrs, from 1925 to 1946. During this period the annual catch averaged about 40 thousand tonnes, making it the largest single-species fishery in the Province (Fig. 4).

The Canadian fishery collapsed without warning in 1947, due to a combination of unfavourable environmental conditions and overfishing, primarily by the U.S. fleet (MacCall 1979, Ware and Thomson 1991). The 1947 annual report by the Canadian Dept. of Fisheries chronicled this passing by noting that "apparently the stocks of mature fish are at a serious low level; and [there is] no prospect of immediate recovery of a sardine fishery of former magnitude off the B.C. coast". The collapse of the northern population began in B.C. then spread south like a row of falling "dominos". Accordingly, the Washington and Oregon fisheries collapsed in 1949, while

the San Francisco Bay fishery collapsed in 1951. In its waning years the northern sardine population showed very little resilience to fishing. MacCall (1979) estimated that the maximum sustainable yield was about 250 thousand tonnes. By the mid-1930s the U.S. fleet was catching about 500 thousand tonnes a year, considerably more than the stock could sustain. Although large catches were only memories by 1953, a small fishery limped along in southern California until the early 1970s.

By the late 1970s, the population showed some signs of recovery. In retrospect, it has been estimated the biomass has been growing at an average compound rate of 24% per year for the last 17 years (Deriso et al 1996). At this rate the population biomass has doubled about every 3 years. The U.S. sardine fishery reopened in 1987 when the population exceeded the minimum fishable biomass required by California State law. By July 1998 the estimated biomass of the sardine stock was 1.6 million tonnes and was declared to be fully recovered by U.S. fishery scientists (Hill et al 1999).

The stock rebuilding that has occurred so far, combined with recent warm oceanic conditions, was sufficient to bring observable quantities of sardines to the west coast of Vancouver Island in 1992 and 1993 for the first time since the late 1940s (Hargreaves et al 1994). Larger numbers were observed in Kyuquot Sound in April 1995, and in Nootka, Kyuquot and Quatsino Sounds in the summer of that year. Mr. Richard Leo found about 5000 tons of sardines in Nootka Sound in October. Obtaining an experimental fishing licence, he made a 100 ton set with a herring purse seine in late November. With this catch, Mr. Leo achieved the distinction of being the first B.C. fisherman to make a commercial sized sardine set since the late 1940s. He made four test sets during December and January 1996 (in Nootka Sound), and caught a total of 148 tonnes of sardines. Half the sets contained about 18% Pacific (Chub) mackerel, and small numbers of Northern anchovy. Eye-witness accounts during the 1920s and 1930s indicate that it was not unusual to find these three species in mixed schools. About 5,000 tonnes of sardines also overwintered along the west coast of Vancouver Island in the Kyuquot/Nootka Sound area during the winter of 1996/97, but for various reasons, were not commercially fished.

Consistent with the migratory behaviour of sardine, the age composition of the catch differs markedly between the US fishery, which operates in southern California, and the B.C. fishery. Age 0,1,2,3 fish make up over 80% of the catch by the US fishery. In contrast, samples from the sardine in B.C. indicate a predominance of age 3, 4, 5 and 6 year old fish (Fig. 3). Historically, the age of sardines caught in the southern California fishery averaged 3 years, and about 5.5 years in the B.C. fishery.

STOCK ASSESSMENT OPTIONS

U.S. Sardine Stock Assessment Practices. Fisheries scientists from the California Department of Fish and Game, National Marine Fisheries Service and other agencies prepare an annual sardine stock assessment and recommended harvest. The CANSAR model is currently used to assess the sardine stock. It is a forward-projecting, age-structured analysis that uses both fishery-dependent

and fishery-independent data to obtain annual estimates of sardine abundance (Hill et al 1999). In 1997 CANSAR was modified into a Two-Area-Migration model, which accounts in part for the fraction of the available biomass outside the range of the California based fishery. Area 1 is centered in the southern California Bight where the fishery and survey data are based. Area 2 includes sardines to the north, south and offshore of Area 1. The migration model is quite simple at this time, since it assumes sardine which leave Area 1 for Area 2 do not return. It is contemplated that future refinements of the model will include more realistic seasonal migration patterns.

The U.S. stock assessment estimated a total coastwide biomass of 1.78 million tons of sardines (on July 1 1998), with 1.18 million tons available to the California and Mexican fisheries (Area 1), and about 601 thousand tons northward (and offshore) of California (Table 2).

The U.S. recommended harvest formula for sardine is:

$$H = (\text{Biomass} - \text{Cutoff}) \times \text{Fraction} \times \text{Stock Distribution}$$

where H is the total California harvest (Area 1 quota); Biomass is the estimated Area 1 biomass of fish age 1+ for the stock at the beginning of season; Cutoff is the lowest biomass where harvest is allowed (currently 165,347 tons); Fraction is the environmentally-dependent fraction of biomass above the Cutoff that can be taken by the fishery and; Stock Distribution is the fraction of the total stock biomass in U.S. Waters (87% in 1999). Fraction is a proxy for F_{msy}, which is the fishing mortality rate to achieve MSY. Fraction depends on ocean temperatures because F_{msy} and sardine productivity are both higher at warmer water temperatures:

$$\text{Fraction} = 0.249\ T^2 - 8.19\ T + 67.46,$$

where T is the average sea surface temperature at Scripps Pier, California during the preceding three seasons (Hill et al 1999). F_{msy} varies between 5 and 15%. For the 1999 fishery Fraction = 15%. Accordingly, the total Area 1(California) sardine quota in 1999 was 132,800 tons.

The current B.C. sardine fishery is still in an experimental harvesting and marketing phase. The costs required to obtain a reasonably accurate inseason biomass estimate of a highly migratory (and unpredictable) species like sardine, which moves freely between inshore and offshore feeding habitats along much of the B.C. coast, are significant. Consequently, at this early stage of development of the B.C. fishery, a cost-effective stock assessment procedure is required to set the maximum allowable catch. Two options are considered.

Option 1: Pre-season B.C. Biomass Estimate

A preseason estimate of the biomass of sardine that will potentially migrate to B.C. can be obtained from the following simple relationship:

$$\text{B.C. biomass (tonnes)} = \text{Total Coastwide Biomass (tonnes)} \times \text{Migration rate} \qquad (1)$$

Migration Rate. Historically, the B.C. fishery took about 10% of the combined U.S. and Canadian catch (Table 1; Fig. 5). Assuming the Canadian and U.S. fisheries harvested the available supply of sardines at about the same rate, then about 10% of the sardine population migrated to B.C. in the summer, on average. Under favorable conditions at current stock levels, this suggests that about 162 thousand tonnes could potentially migrate to B.C. in the summer. Table 2 indicates that about 34% of the total biomass of sardine is estimated to be northward (and seaward) of the southern California fishery (Table 2, Area 2 biomass). Since about 30% (0.1/0.34) of this biomass appears to migrate to B.C. during the summer, the remaining 70% is presumably dispersed between Northern California and the US-Canada border (Fig. 1).

Option 2. Inseason Biomass Estimate. A weakness of the preceeding option is that significant year-to-year deviations in the migration rate from the average value can be expected when ocean temperatures (and other factors that we don't understand yet) change (Fig. 5). Ideally, a 'synoptic' summer, stock assessment survey is required to assess the size of the sardine stock in B.C. An efficient way to use the available commercial and DFO research vessels would be to combine an inshore survey with a concurrent offshore survey. The inshore survey (overseen by DFO approved observers) could be completed by the sardine seine fleet (at their expense) during late July/August, when sardines are still abundant in Canadian waters and are nearing their peak body condition. This inshore survey should coincide with an offshore, DFO midwater trawl survey designed to obtain a swept-volume estimate of the biomass of sardine off the west coast of Vancouver Island (and Queen Charlotte Sound if required). The resulting inshore and offshore assessments could be combined to obtain an estimate of the total sardine biomass in B.C.

However, a serious obstacle to implementing this approach is that B.C. sardine fishermen have found it difficult to assess the biomass of sardine using conventional fishing sonars. Also, because of the patchy distribution of sardine there is likely to be a large uncertainty in the biomass estimated by an offshore trawl survey. Accordingly, it is not clear at this point if Option 2 can be done accurately enough to make it a significant improvement over the first option, which is considerably less expensive.

Harvest Rate. The US is currently harvesting the northern stock at an average rate of 10% (range of 5 to 15%) of the biomass available to the California fishery, and has a cutoff biomass of 149 thousand tonnes. To be precautionary, Canada should also harvest the sardine stock at a rate which does not exceed 10% of the estimated preseason (or, if available, the inseason) biomass of sardines in Canadian waters. Accordingly, the recommended harvest formula is:

B.C. Catch (tonnes) = [(Biomass - Cutoff) x Fraction] x B.C. Migration rate x Harvest Rate

$$= [(1{,}617{,}600 - 149{,}000) \times 0.87] \times 0.10 \times 0.10$$

This yields a maximum potential catch of 12,700 tonnes. However, for management reasons such as: 1) an undesirable bycatch of sensitive species like coho and chinook salmon or; 2) the appearance of sardines in environmentally sensitive (or unfishable) areas) it would be advisable to lower the Harvest rate to around 5% until the B.C. sardine fishermen are more experienced, and the bycatch risks associated with the fishery are more clearly defined.

CONCLUSIONS

1. The oldest age-groups of Pacific sardine in the northern population migrate northward from California to B.C. in the summer, and complete a return migration in the fall. The northern population ranges from southern California to B.C.

2. The migratory behaviour of sardine is complex and poorly understood. However, one generalization which emerges from historical and recent accounts is that sardines are particularly abundant off B.C. in warm summers, when the northern population biomass exceeds 1 million tonnes. Both conditions appear necessary to produce a large run.

3. Historically, an average of 10% of the northern stock appears to have migrated to B.C. The actual percentage varied from year-to-year in response to changes in water temperature, and other factors. The U.S. is currently harvesting the portion of the northern stock available to the California fishery at an average rate of 10%. To be precautionary, the Canadian harvest rate should not exceed the U.S. rate.

4. Until more scientific information is available with respect to: 1) an undesirable bycatch of sensitive species like coho and chinook salmon, and 2) the appearence of sardines in sensitive (or unfishable) areas, it would be advisable to lower the B.C. harvest rate to around 5% for a few years, until B.C. sardine fishermen become more experienced, and the bycatch risks associated with the fishery are more clearly known.

5. DFO must make it very clear to the sardine industry from the outset that the allowable sardine catch is a ceiling, not a target. Because of the dynamic and unpredictable movements of this highly migratory species there is no guarantee that the B.C. sardine fleet will catch the annual quota. Industry must also be aware that sardine undergo large fluctuations in abundance in response to variations in ocean climate. Accordingly, if the currently favourable conditions deteriorate the sardine could suddenly 'disappear' from the B.C. coast (for a while at least), like they did in the late 1940s. The long-range potential for the sardine fishery depends on how the northern stock responds to the potential increase in coastal temperatures in the northeast Pacific caused by global warming. To fully appreciate the unpredictability of the sardine fishery one should take a long, hard look at Figure 4.

6. Regardless of whether a preseason or inseason biomass estimate is used to determine the total allowable catch, soundings should be conducted in inshore waters to estimate the relative biomass of sardines in the area before a fishery commences. In-season management should be used to balance the catch among areas to allow for a precautionary treatment of potential

ecosystem impacts. This requirement recognizes that sardines are a potential forage fish for chinook, some groundfish species, and marine mammals.

7. All fisheries should be supervised by a DFO approved observer, who is also responsible for obtaining set logs, biological samples and other relevant data from the fishery and forwarding it to the Pacific Biological Station, Stock Assessment Division.

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Table 1. Total U.S. and B.C. sardine catch (thousands of tonnes) and percent of total catch landed in British Columbia.

Year	Total	British Columbia	Percent
1917	65.90	0.07	0.11
1918	71.81	3.3	4.59
1919	63.77	3.0	4.70
1920	38.86	4.0	10.29
1921	34.00	0.9	2.64
1922	59.97	0.9	1.5
1923	77.00	0.9	1.1
1924	158.17	1.24	0.8
1925	138.97	14.47	10.4
1926	182.04	43.99	24.1
1927	231.91	62.10	26.8
1928	303.83	73.04	24.0
1929	373.24	78.33	21.0
1930	235.99	68.10	28.8
1931	216.09	66.76	30.9
1932	267.60	40.23	15.0
1933	351.44	5.49	1.5
1934	578.71	39.01	6.7
1935	573.28	41.33	7.2
1936	717.74	40.32	5.6
1937	452.05	43.62	9.6
1938	608.19	46.96	7.7
1939	528.67	5.01	0.9
1940	447.44	26.10	5.8
1941	617.10	54.48	8.8
1942	519.77	59.76	11.5
1943	525.27	80.50	15.3
1944	556.94	53.63	9.6
1945	399.43	31.12	7.8
1946	224.84	3.6	1.6
1947	118.01	0.44	0.4
1948	171.51	0.00	.
Mean	**309.67**	**31.02**	**9.6**

Table 2. Estimated biomass of sardine in the total stock, and in the offshore and northern region (Area 2, which includes northern California, Oregon, Washington and British Columbia). The original estimates from Hill et al (1999) are in short tons.

	Short tons	Metric tons
Total stock biomass (age 1+)	1,783,500	1,617,600
Area 2 biomass	601,000	545,000
Area 2 biomass/Total biomass	34%	34%

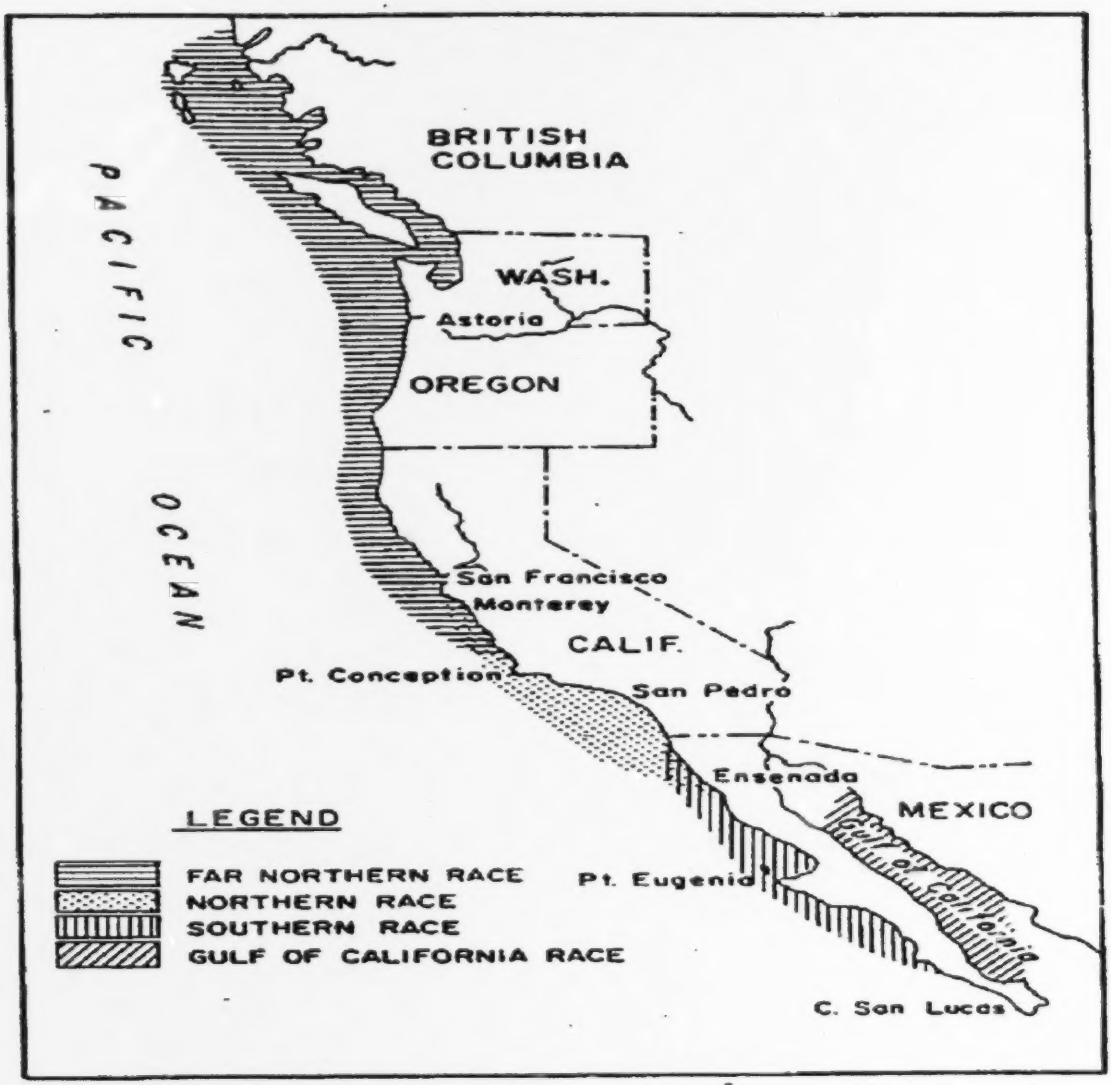

Fig.1 Diagramatic representation of four partially intermingling stocks of Pacific sardines. The far northern stock is suggested from studies of age and growth, and Population dynamics. All stocks tended to range further south during winters of cold Years and further north during summers of warm years. (From Radovich 1982).

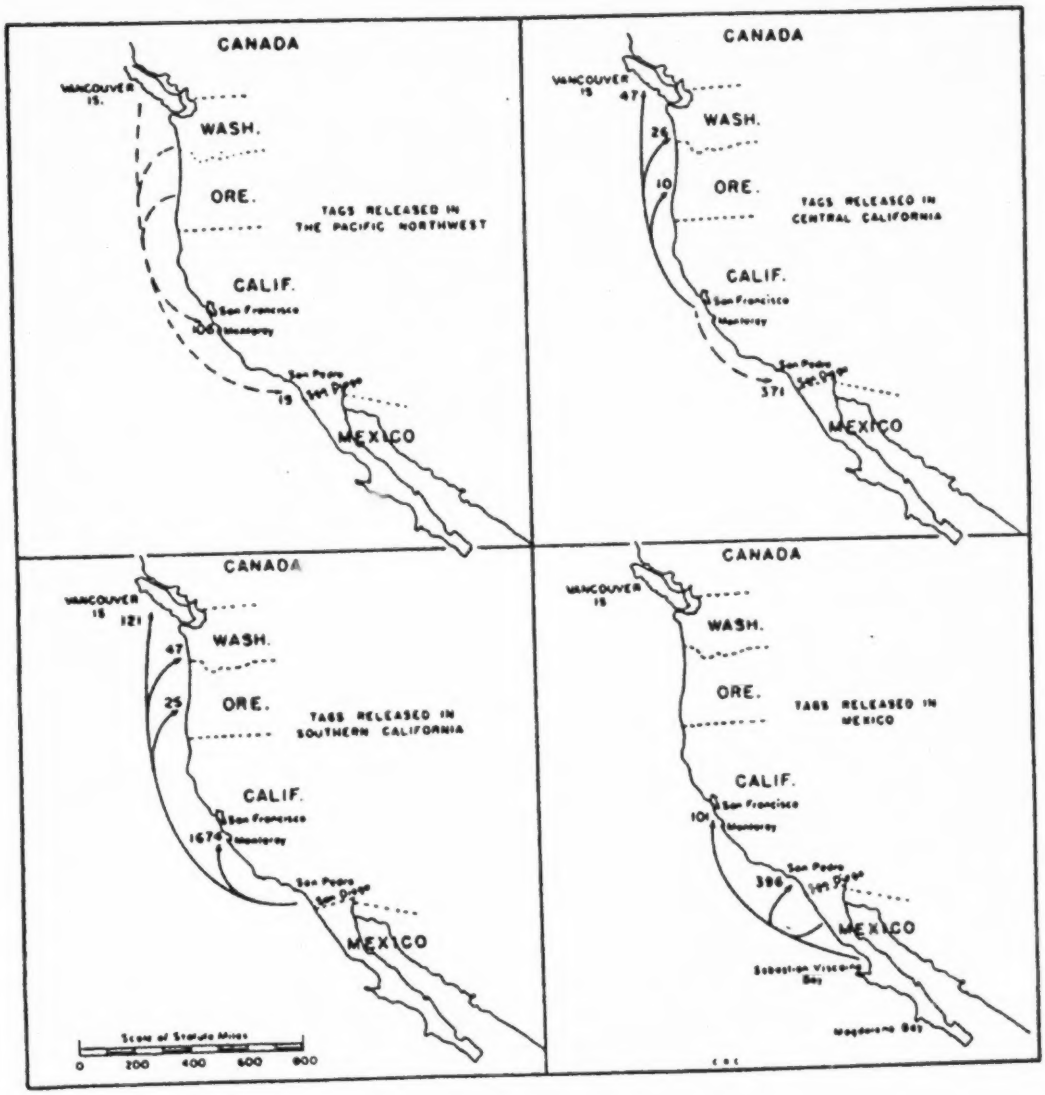

Fig. 2. Sections of the Pacific coast of North America showing the major movements of tagged sardines as indicated by recoveries from June 1935 to May 1944. (From Clark and Janssen, 1945)

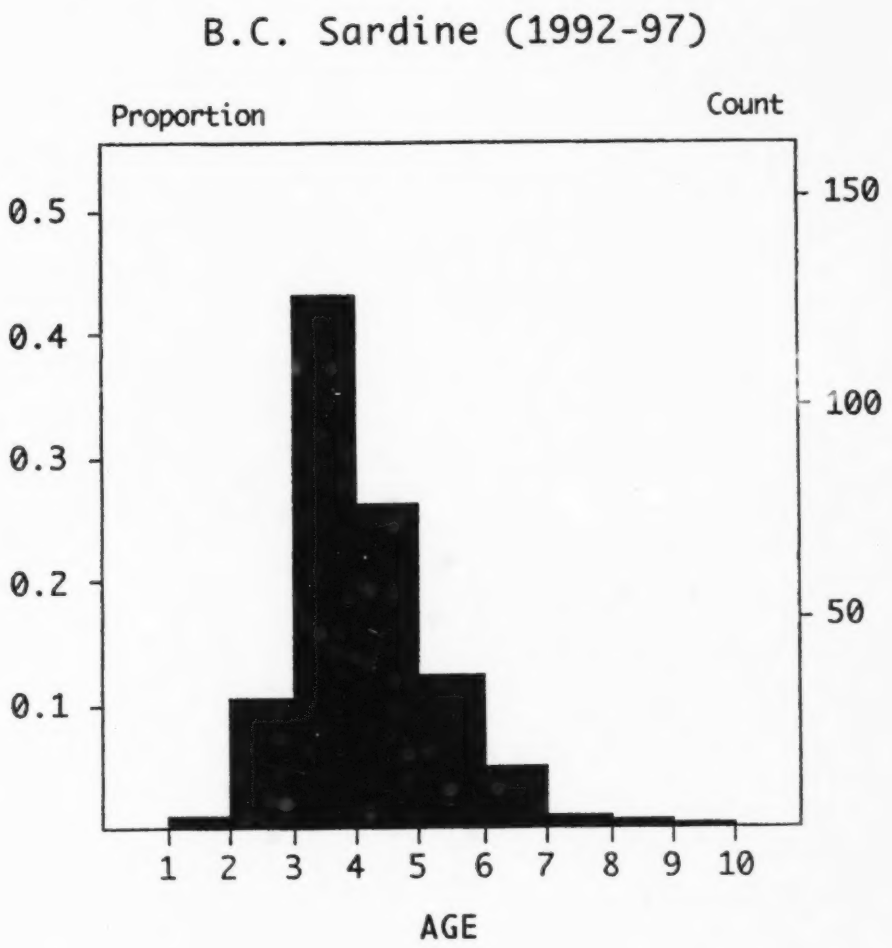

Fig. 3. Age composition (years) of sardines captured during DFO research surveys along the west coast of Vancouver Island between 1992 and 1997. Experienced staff in the California Fish and Game Department determined the sardine ages in these samples.

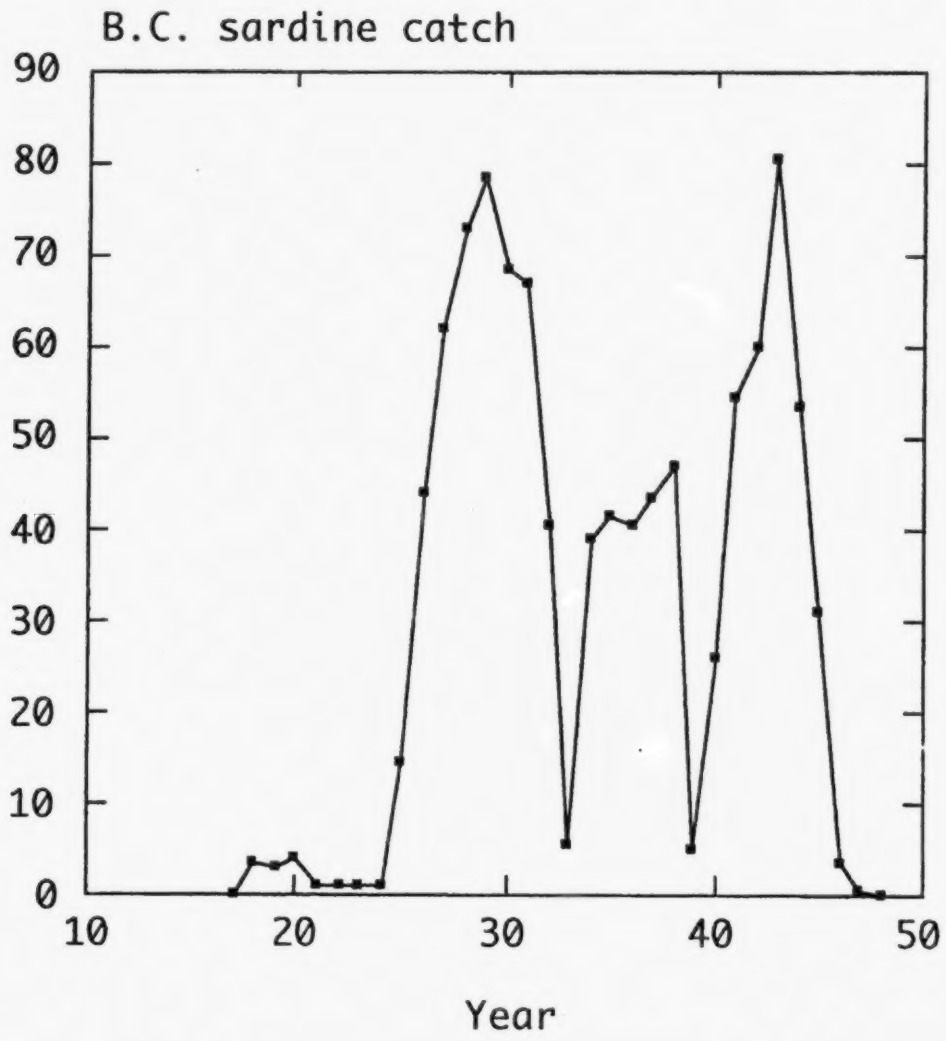

Fig. 4. British Columbia sardine catch (thousands of tonnes) between 1917 and 1947.

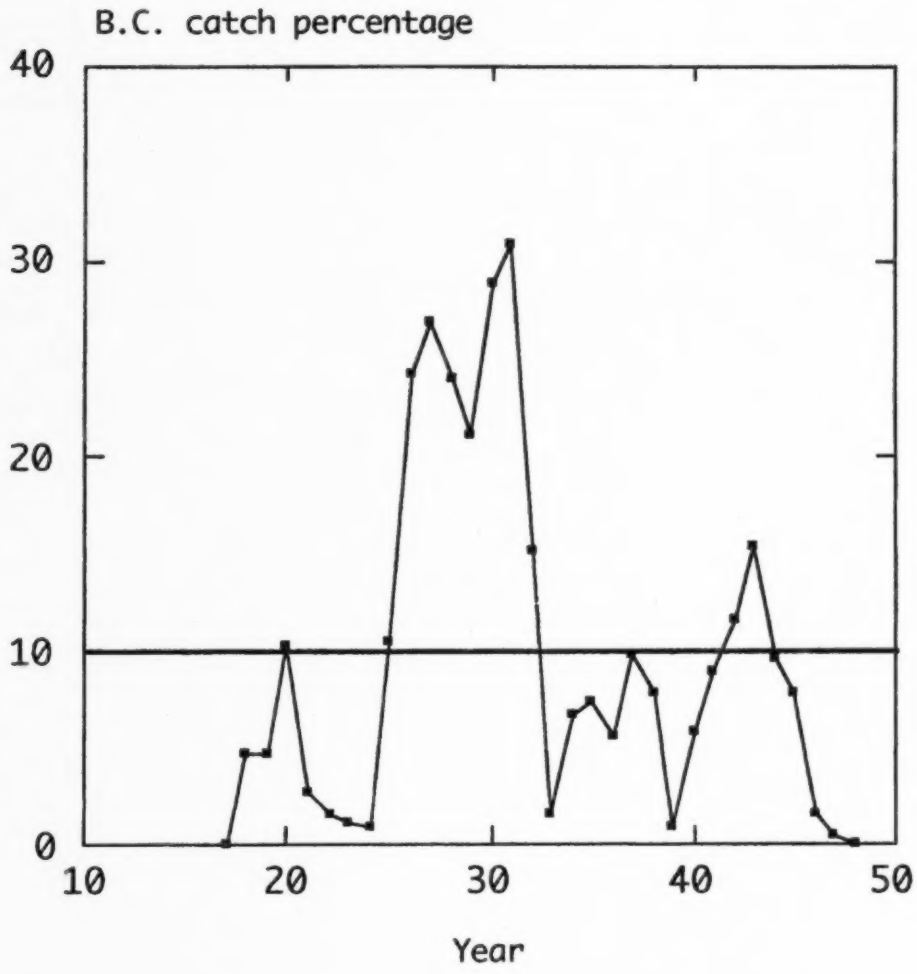

Fig. 5. Percentage of the combined US and Canadian sardine catch landed in British Columbia. The average is 10%. However, there were extended periods where the fraction was appreciably higher (e.g. 1926 to 1932), and lower (e.g. 1933 to 1941).